ANTICIPATION AND VISUAL SEARCH IN ELITE SPORT: THE EFFECTS OF ANXIETY, TRAINING AND EXPERTISE.

DAVID B. ALDER

A thesis submitted in partial fulfilment of the requirements of

Liverpool John Moores University for the degree of

Doctor of Philosophy

September 2014

Contents

Acknowledgements………………………………………………………		3
List of Tables and Figures………………………………………………...		4
Abstract…………………………………………….............................		6
Chapter 1:	Review of perceptual-cognitive skill and the potential for training and transfer……………………………………….	7
Chapter 2:	The coupling between gaze behaviour and opponent kinematics during successful anticipation of badminton serves……………………………………………………...	30
Chapter 3:	Skilled anticipation in racket sports: profiling an exceptional badminton player………………………………………….	32
Chapter 4:	The effects of anxiety on the anticipation performance, resource allocation and visual search behaviour of skilled and novice badminton players……………………………….	34
Chapter 5:	Does training under anxiety facilitate transfer of learning in elite performers?	36
Chapter 6:	Epilogue...	38
Chapter 7:	References..	58

Acknowledgments

First and foremost I would like to thank my supervisors Dr Paul R. Ford, Dr Joe Causer and Professor Mark Williams for their support, guidance and unwavering standards throughout the last three years. I would also like to thank the post-graduate community at LJMU. The environment in the office was great fun to be a part of; I will not however miss the lack of windows! But specifically to David Broadbent, without your help on those early morning trips to Milton Keynes this thesis would not have been possible! To Oliver Logan at the English Institute of Sport, I am extremely grateful for you providing me with the network of contacts, the opportunity for personal development and finally for believing in what I was about and what I capable of achieving. I would like to thank Julian Robertson and Simon Drane for their help in organising data collection and for being so accommodating during each testing session.

To anyone who has come in and out of my life over the last three years, thank you for helping shape the person I have now become. I must acknowledge the great set of friends I have established in Liverpool over the last three years but especially Andy O'Keefe, Luke Topping, Paddy Walsh and Rob Seaborne. Thank you for providing me with plenty of opportunities to distract me from the stresses of the PhD, some more advisable than others!

I would like to dedicate this thesis to my mum, dad and sister. You have always shown absolute faith in me; not bad for someone who turned up to do his G.C.S.E exams with just a lottery pen! You have provided support through so many mechanisms, and for that I will be forever grateful. This thesis is also dedicated to both sets of my grandparents, without their financial and emotional backing I would not be the person I am today. I hope I have done you all proud.

List of Tables and Figures

1.1 Kinematic analysis of the 3rd carpal on right wrist for a representative participant, where a) Distance travelled b) Velocity c) Acceleration. The vertical dotted lines indicate the frame in which the preparation phase ended and execution phase started ………………………………………… NA

1.2 Mean (SD) distance travelled (mm) in the preparation phase of the serve for the seven markers that differentiated long from short serves in one of the two phases……………………………………………………………... NA

1.3 Mean (SD) distance travelled (mm) in the execution phase of the serve for the seven markers that differentiated long from short serves in one of the two phases……………………………………………………………... NA

1.4 Mean (SD) peak acceleration (mm) in the execution phase of the serve for the seven markers that differentiated long from short serves in one of the two phase……………………………………………………………… NA

1.5 The six service locations used in the laboratory-based temporal occlusion anticipation test……………………………………………………………… NA

1.6 Timeline of each video clip in the temporal occlusion anticipation test……. NA

1.7 Mean (SD) response accuracy of the expert and novice groups on the temporal occlusion anticipation test……………………………………… NA

1.8 Inferential statistics for visual fixation location data in the execution phase of the movement for the expert and novice group on successful and unsuccessful trials………………………………………………………… NA

1.9 Mean (SD) visual fixation locations for the expert and novice groups in the execution phase of the movement…………………………………………... NA

2.1 The experimental set-up of the temporal occlusion anticipation test……….. NA

2.2 Anticipation judgement accuracy (number of trials) for the three participants on the temporal occlusion test…………………………………. NA

2.3 Errors by the three participants on the temporal occlusion anticipation test... NA

2.4 Representative scan paths of (a) long final fixation and (b) main scan paths (bottom panels) for each participant. The larger the circle or thicker the black line the greater the frequency. Circles depict fixations and not eye movement trace…………………………………………………………... NA

3.1 Mean (SD) scores on each MRF-3 subscale for both groups across anxiety conditions………………………………………………………………… NA

3.2 Inferential statistics from MANOVA on MRF-3 subscales for both groups across anxiety conditions…………………………………………………. NA

3.3 Mean (SD) response accuracy (number of trials) on the primary anticipation judgement task for the skilled and novice badminton players in the high and low-anxiety conditions……………………………………… NA

3.4 Mean (SD) response time (ms) on the secondary tone recognition task for the skilled and novice badminton players in the high and low-anxiety conditions…………………………………………………………….... NA

3.5 Inferential statistics of the ANOVA for the number visual fixations as a function of group and anxiety condition……………………………………. NA

3.6 Inferential statistics of the ANOVA for the duration of visual fixations as a function of group and anxiety condition…………………………………… NA

4.1 Timeline of testing protocol……………………………………………… NA

4.2 Mean (SD) for each subscale of the MRF-3 and the RSME in the laboratory-based sessions………………………………………………… NA

4.3 Inferential statistics for the MRF-3 and the RSME in the laboratory-based sessions………………………………………………………………… NA

4.4 Mean (SD) response accuracy (number of trials) for each group on the laboratory-based sessions………………………………………………… NA

4.5 Mean (SD) response accuracy (number of trials) for each group on the field-based sessions……………………………………………………. NA

4.6 Mean (SD) number of fixations and duration of final fixation (ms) in the laboratory and field-based sessions……………………………………..... NA

4.7 Inferential statistics for the number of fixations and duration of final fixation in the laboratory and field-based sessions …………………………. NA

4.8 Mean (SD) for each subscale of the MRF-3 and the RSME across the testing phase………………………………………………………………… NA

4.9 Inferential statistics for the MRF-3 and the RSME across the testing phase.. NA

4.10 Response accuracy for both training groups across the training phase…….. NA

Abstract

The aim of this thesis was to examine the influence of high-anxiety, training and expertise-level on perceptual-cognitive skills in the sport of badminton. First, the coupling between observed badminton serves, visual search behaviour and anticipation judgements of athletes ranging in expertise was investigated. Expert players produced more accurate anticipation judgements compared to novice athletes. Experts fixated vision upon body areas containing the discriminating kinematic information between serve-types more frequently and for a longer duration compared to novice players. A subsequent case-study highlighted the relationship between expertise, visual search and anticipation judgement extended to a world-class athlete. Second, the role of skill level in mediating the effects of high anxiety on anticipation and the capacity to allocate attentional resources to a secondary task was examined through high- and low-anxiety conditions. Skilled players made more accurate anticipation judgements compared to their novice counterparts, regardless of anxiety conditions. High-anxiety resulted in a decrease in secondary task performance for the novice, but not the skilled group, when compared to low-anxiety. Finding demonstrates that skilled athletes can effectively allocate attentional resources during performance, leading to the effects of anxiety being negated, whereas novices cannot. Third, a perceptual-cognitive intervention consisting of simulation training under high-anxiety conditions led to greater anticipation performance under high-anxiety and field-based conditions compared to pre-test and training under low-anxiety conditions. Overall, expert athletes make superior anticipation judgements due to different visual search behaviours and attentional resources, all of which are robust to high anxiety, when compared to lesser-skilled players, with these abilities being trainable.

Chapter 1: Review of perceptual-cognitive skill, anxiety, visual search and expertise in sport

Expertise is defined as the ability to consistently produce superior levels of performance at specific tasks in a domain over an extended period of time (Starkes, 1993). It has been examined across a range of domains, including academia (e.g., Sternberg, 1998), music (e.g., Besson, Schon, Moreno, Santos & Magne, 2007) and sport (e.g., Williams, Ward, Bell-Walker & Ford, 2012). One of the main findings from researchers examining expertise is that a range of perceptual and cognitive skills underpin performance. Perceptual-cognitive skill refers to the ability of an individual to locate, identify and process environmental information so as to integrate it with existing knowledge in order to select and execute appropriate actions (Broadbent, Causer, Ford & Williams, in press). In this chapter, a review of research on perceptual-cognitive skill, perception-action coupling and memory is provided, as well as a review of the effect of high-anxiety, training and expertise on these skills.

The main framework used to examine expertise in recent years has been the *Expert Performance Approach* (Ericsson & Kintsch, 1995). The three-stage framework was developed in order to empirically examine expert performance due to dissatisfaction with the common "talent-based" view that expertise is the result of greater intellect, is pre-determined, or is the same variable as experience. The first stage of the approach consists of measurement of performance on challenging domain-specific tasks that capture the key aspects of performance in that domain. These tasks should be representative to the domain and reproducible in nature. The second stage examines the mechanisms that underpin superior performance on the task, such as visual search behaviour or cognitive thought processes (Williams & Ericsson, 2005). The final stage investigates how the mechanisms were acquired through measuring the specific developmental activities that experts had engaged in to aid in their acquisition (Ericsson, 2003).

A key finding from researchers working within or in parallel with the Expert Performance Approach is that performance in a range of domains are underpinned by similar perceptual and cognitive skills. Perceptual-cognitive skills have been shown to be essential to aiding everyday tasks, such as driving (Lewin, 1982), identifying gender through gait (Loula, Prasad, Harber, & Shiffrar, 2005) and simple motor tasks (i.e. a reaching task; Creem & Proffitt, 2001). However, these skills have been shown to be key in a range of specialist domains of expertise, including medicine (Causer & Williams, 2013), the military (Ward, Farrow, Harris, Williams, Eccles, & Ericsson, 2008) and sporting environments (Roca, Ford, McRobert & Williams, 2013). In sport, expert athletes clearly possess several other attributes that underpin their superior performance over less-skilled athletes (Williams & Reilly, 2000) including: physiological (Reilly, Bangsbo & Franks, 2000), tactical (Wheeler, Wiseman & Lyons, 2011) and psychological (Spieler, Czech, Joyner, Munkasy, Gentner & Long, 2007) attributes. However, as athletes in some sports progress along the expertise continuum, the amount of influence of these other attributes diminishes between expert and sub-expert performance, particularly in skill-based sports. It is at this stage that psychological and perceptual-cognitive attributes become more likely to differentiate expert and sub-expert athletes, when compared to physical and physiological factors alone (Williams & Reilly, 2000).

In the next section, the key perceptual-cognitive skills that differentiate expert athletic performance from lesser-skilled performance are reviewed. These skills include anticipation and its underlying skills of advanced cue utilisation, assessing situational probabilities and structure recognition, as well as the underlying processes of visual search and memory.

Perceptual-cognitive skills

Anticipation

A key perceptual-cognitive skill within a sporting context is the ability to anticipate opponent actions prior to their completion (Abernethy & Russell, 1987). *Anticipation* is defined as the ability to predict upcoming opponent actions in order to allow sufficient time for an appropriate response (Broadbent et al., in press). In sports tasks, where strict temporal constraints are placed upon the athlete, the ability to accurately anticipate an upcoming action has been shown to be a pre-requisite in producing sporting excellence (Roca, Ford, McRobert & Williams, 2011). Researchers have consistently shown that expert athletes are significantly more accurate at anticipating opponent actions compared to lesser-skilled athletes (for a review, see Williams & Ford, 2008). A significant body of research has examined the underlying skills, mechanisms and attributes required to anticipate an action. These underlying skills, mechanisms and attributes of anticipation are reviewed in the following sections.

Advance cue utilisation. Expert athletes are able to anticipate opponent actions prior to the action being completed. They do so by identifying information-rich areas from within the visual display and interpreting the link between the cues emanating from that location and the subsequent action (Abernethy & Zawi, 2007). The ability to identify advanced cues is an essential in successful motor performance as often the limitations of reaction and movement times result in the execution of the correct motor response occurring too late (Triolet, Benguigui, Runigo & Williams, 2013). One of the earliest studies to investigate advance cue utilisation was completed by Abernethy and Russell (1987). Expert and novice badminton players were required to anticipate badminton shots that were occluded around racket-shuttle contact. Expert players were significantly more accurate than novices at anticipating shot location and able to anticipate shot location at a significantly higher level than chance at up to 83 ms prior to shuttle contact. Finding suggests that relevant information regarding an upcoming action is present even at this advanced time point. Expert athletes are able to process the link between these cues and the subsequent action more efficiently compared to less-expert athletes.

Two traditional approaches have been used to examine the concept of advance cue utilisation. First, the *temporal occlusion paradigm* in which life-sized video of opponent actions is occluded around a key event (e.g. foot-ball or racket-ball contact) (Abernethy, 1990; Abernethy & Russell, 1987; Farrow, Abernethy, & Jackson, 2005; Salmela & Fiorito, 1979; Savelsbergh, van der Kamp, Williams & Ward, 2005; Williams & Burwitz, 1993; Williams & Elliott, 1999). For example, Abernethy, Gills, Pack and Packer (2001) examined expert and novice squash players who were presented with life-sized videos of opponents completing a number of smash shots. The video was occluded at a range of time points in relation to the racket-ball contact (-160 ms, -80 ms, racket-ball contact and +80 ms). Participants were required to anticipate the force/direction of the smashes. Expert athletes demonstrated more accurate anticipation judgements than the novices at each occlusion point. The temporal occlusion paradigm identifies the specific time-points across an action at which information regarding an upcoming movement becomes available. However, it does not reveal the specific regions or locations of the body at which the between-movement differences are occurring.

A second approach for examining cue utilisation and the regions or locations of the observed body involved is the *spatial occlusion paradigm*. It consists of life-sized video of opponent actions being presented with areas of the display being either removed (e.g., full body is observable except the serving arm and racket), or presented in isolation (e.g., only the arm and racket is visible) (Abernethy & Russell, 1987; Williams & Davids, 1998). Panchuk and Vickers (2009) used the spatial occlusion paradigm to examine the cues used by elite ice hockey goalkeepers anticipating opponent flicks. Four conditions were created in which specific areas of the opponent were occluded (upper body, lower body, stick and puck). Participants were able to anticipate at a greater level than chance when the upper and lower body were occluded. However, when the stick or the puck was occluded, the accuracy of anticipation judgement significantly decreased. The spatial occlusion paradigm highlights the specific areas within the display in which advanced information regarding the movement is originating. Expert athletes may be able to utilise alternative sources of information when a specific cue is occluded whereas lesser-skilled athletes cannot. Also it may not the occluded area that contains the discriminatory information, but the relative motion or relationship between the occluded area and another, or it may act as an ‘anchor’ or pivot point. However, this approach does not identify the time points during an action in which this information becomes available, nor does it reveal the role of relative motion or the relationship between cues.

Structure recognition. Expert athletes are superior at recognising complex patterns within a series of play compared to their less-expert counterparts (Allard, Graham & Paarsalu, 1980; Williams, Hodges, North, & Barton, 2006). The ability to recall patterns in play aids anticipation of their outcome. For example, North, Williams, Hodges, Ward and Ericsson (2009) had expert and less-expert soccer players view video sequences of soccer matches that were occluded at various points in play. They were required to anticipate the next move made by the player in possession of the ball at the point of occlusion. In a subsequent phase, they were tasked with identifying sequences they had viewed previously. Expert players were more accurate than the less-skilled players at anticipating the action the player with the ball was about to make. Experts also demonstrated superior ability to identify the sequences they had previously viewed, whereas less-skilled players could not differentiate previously seen from new clips. It is suggested that expert athletes are able to link together multiple interacting sources of information from within the sporting display, such as the location of teammates/opponents in relation to the ball. This ability allows them to store the information sources as single structures or templates within working memory, which they can later recall when required, as opposed to storing and recalling each individual source. In contrast, less-expert athletes seemingly rely heavily upon superficial background features in isolation when recalling previously seen footage (Chase & Simon, 1973; Williams et al., 2006).

Situational probabilities. Expert athletes are able to rank possible outcomes of an evolving situation more efficiently than less-expert athletes, through the extraction of task relevant contextual information from within the display. Support for this notion was provided in Ward and Williams' (2003) study of elite and sub-elite soccer players. Participants were presented with a variety of match-play scenarios that were occluded at key points during the pattern of play. They were required to rank the player(s) in the most beneficial position to receive the ball at the point of occlusion. The elite group identified a greater number of options compared to the sub-elite group. They were more accurate at ranking the options they had identified in regard to the amount of threat the option posed to the defence. The elite group have an extensive amount of domain-specific knowledge enabling them to compare the characteristics of the current environment with situations previously encountered in order to identify and rank the likelihood of possible outcomes. In contrast, less-expert athletes do not have the wealth of knowledge so they cannot do so, or do so to a lesser degree (McRobert, Ward, Eccles, & Williams, 2011).

Perceptual-cognitive processes

Visual search behaviours. Expert athletes have been shown to exhibit significantly different visual search behaviours compared to less-expert athletes (Ward, Williams & Bennett, 2002). These behaviours allow them to consistently anticipate upcoming actions to a superior level (Savelsbergh, Williams, van der Kamp & Ward, 2002). Expert athletes have been shown to not possess superior visual acuity compared to their less-expert counterparts (Ward & Williams, 2003). Rather, it is specific characteristics of visual search that contribute to the expertise-related differences in perceptual-cognitive judgements (Mann, Williams, Ward & Janelle, 2007). Traditionally, frequency and duration of visual fixations and the amount of time spent fixating specific areas/regions of the display are examined to highlight the mechanistic differences between skill-groups.

For example, Savelsbergh et al. (2002) examined expert and novice soccer goalkeepers who were required to anticipate video of penalty kicks occluded at ball contact whilst having their visual search behaviour measured. Expert goalkeepers were significantly more accurate at anticipating penalty kick direction compared to the novice group. They demonstrated significantly different visual search behaviours compared to the novices. Experts made fewer fixations of longer duration to less disparate areas of the display compared to the novice participants. These findings support those of other researchers who have shown expert visual search behaviour consists of using fewer fixations of a greater duration (Canal-Bruland, Lotz, Hagemann, Schorer & Strauss, 2011; Mann et al., 2007). This strategy allows for maximal information processing of the observed cue and suppresses the chance of distractibility to irrelevant stimuli. In the Savelsbergh et al. (2002) study, expert goalkeepers fixated the kicking leg, non-kicking leg and the ball more frequently compared to novices, particularly as the moment of foot-ball contact approached. In contrast, the novice goalkeepers spent longer periods of time fixating on the trunk, arms and hips. A key difference between expert and less-expert athletes appears to be their ability to search the sporting display, identify key visual information, and interpret the link between the identified cue and action to make judgments.

Measuring visual search behaviour not only reveals differences related to skill level (e.g. Savelsbergh et al., 2002), but also the proficiency of individuals at a specific task (Ripoll, Bard, & Paillard, 1986; Vickers, 1992). For example, Savelsbergh et al. (2005) report how the visual search behaviour of expert soccer goalkeepers anticipating penalty kicks differed as a function of success at the judgment. On successful anticipation judgements the goalkeepers spent greater periods of time fixating the non-kicking leg compared to unsuccessful judgments, whereas on unsuccessful judgements they fixated the head for greater periods of time. Data suggests visual search behaviour and the outcome of performance are inextricably linked, with the previous having the potential to both positively and negatively impact upon the latter.

Visual search behaviour can also differ as function of the task constraints present within a situation. For example, Roca et al. (2013) showed that expert and less-expert soccer players anticipating opponent actions had visual search behaviours that changed as a function of the task. In a condition in which the ball was located far away in the opponent's half of the field, players made more fixations of a shorter duration to a greater number of locations in the display (i.e., opponents, teammates, and areas of free space). However, when the ball was located nearby in their own team's half of the field, players made fewer fixations of a longer duration and fixated mostly toward the player in possession of the ball. In this situation, expert players may use the player they are fixating upon as an “anchor point”, allowing peripheral vision to extract information from more distal areas of the display. Similarly, Ripoll et al. (1995) found that boxers used an “anchor point” when facing attacks. They had expert, intermediate and novice boxers view attacks on a screen. Participants were required to respond by completing previously learned joystick manoeuvres and visual search behaviour was measured throughout. Expert boxers made more accurate joysticks responses compared to the less-expert groups, along with exhibiting different visual search behaviour. Experts fixated upon specific areas of their opponents’ body using central vision, such as the opponent’s head, whilst using peripheral vision to search for task-relevant cues. Once a cue was detected, such as the arm/fist, they shifted their fixation onto it in order to process the link between the cue and the forthcoming action so as to anticipate it. Data shows the visual search behaviour required to accurately anticipate an action is inextricably linked to the required response (Travassos, Araujo, Davids, O’Hara, Leito, & Cortinhas, 2013).

Expert athletes are not only superior at locating the key areas of the display to fixate vision upon, but are better at processing the link between the current environmental cues and the upcoming action. For example, Abernethy and Russell (1987 had expert and novice badminton players anticipate opponent strokes on a temporal occlusion test. Expert players produced more accurate anticipation judgements compared to the novice players. However, there were no between-group differences in the visual search behaviours of frequency, duration and sequence of fixations. The between-group differences in anticipation judgement accuracy were explained by the clear difference between orientating vision toward a specific region (i.e., “looking”) and extracting information from an identified region (i.e., “seeing”). Experts were able to better extract task-salient information from within the specific areas of the display they fixated upon (Ward et al., 2002).

Memory. Experts have been shown to possess superior storage and retrieval strategies/mechanisms compared to less-expert athletes. These memory differences occur in structured domain-specific situations, such as the Pirc Defence opening in chess, as opposed to unstructured, non-domain specific memory, (i.e. randomly arranged pieces on the board; see de Groot, 1965). Expert athletes develop complex skills that allow them to either avoid or simply manipulate the limits of working memory (Ericsson & Kintsch, 1995). Ericsson and Kintsch (1995) termed this *long-term working memory* because it has the capacity of long-term memory, but the encoding and retrieval speed of short-term memory. The skills lead to the rapid encoding of domain-specific information in long-term memory and enable quick access to this information when required, circumventing the constraints of normal long-term memory. Moreover, experts store domain-specific information in a structured manner that allows them to anticipate future retrieval demands. Cues stored in short-term working memory allow immediate and efficient access to the information stored in long-term memory. It provides the expert performer with greater capacity to engage in planning, reasoning, evaluation, and other key activities needed for performance (Ericsson & Delaney, 1999). It is postulated that domain specific memory/knowledge and more efficient memory structures of expert athletes are built up through deliberate practice and prolonged engagement in the task (Ford & Williams, 2008).

Issues for perceptual-cognitive skills research

Researchers examining perceptual-cognitive skills must consider other factors that may impact their findings. First, there is a need to consider the link between perception and action and how it influences findings. Second, competition-like stressors can lead to decrements in perceptual-cognitive skill performance and specific training interventions should be considered to mediate these potentially negative effects.

Perception-action coupling

Early research examining the perceptual-cognitive skills of athletes has been criticised for using small, static visual displays that are thought to limit the expert advantage (Williams & Grant, 1999). Issues were raised regarding the ecological validity of these tasks and concerns have been raised about how closely tasks and actions in the laboratory replicate those found in the real-world (Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). Recent work has moved onto utilising perception-action coupling, also known as the vision-in-action paradigm (Vickers, 2007). This paradigm provides the most representative view of the visual search behaviour utilised during performance. The paradigm groups athletes based upon objective standards of performance (i.e. race times), requires them to complete sport representative tasks and then compares the visual search behaviour between the groups along with examining the specific behaviour as a function of success. It provides information as to the visual search behaviour in three-dimensional space thus providing quantifiable information on the full length, breadth and depth of the visuo-motor workspace. Pinder, Davids, Renshaw & Araujo (2011a) describe how *task functionality* and *task fidelity* are two critical components when designing a training environment. The functionality of the task refers to the perceptual, cognitive and motor constraints of the environment and the need for them to match the real-world version of the task. Similarly, the fidelity of the action requires that the response provided by the performer is matches what they complete in the performance environment. A recent meta-analysis showed that in studies examining the perceptual-cognitive skills of expert and novice participants the differences between the two groups were directly proportional to how close the action completed in a simulated environment is to the actual action required in sport (Travassos et al., 2013).

Dicks, Button and Davids (2010) provided a test of perception-action coupling in recreational soccer goalkeepers facing penalty kicks. Participants were required to anticipate soccer penalty kicks in a number of conditions that demanded differing types of responses whilst having their visual search behaviour measured. The response conditions were verbal responses, joystick movement, simplified body movement and full body movement. Participants visual search behaviour changed as a function of the type of response required. In conditions that required limited movement (i.e. verbal responses, joystick movement and simplified body movement) participants spent more time fixating upon the movements of the penalty taker in comparison to the ball location. In comparison, in the condition that required an interceptive movement (i.e. attempting to save the penalty), participants spent a greater amount of time fixating upon the ball location. Data demonstrates that to accurately examine perceptual-cognitive judgements and their underpinning mechanisms it is essential that representative experimental conditions are employed. However, a key limitation of this study is that the interceptive condition had less possible goal location options (n = 2) than the non-interceptive conditions (n = 6), which may have led to the observed findings. More work is required in order to identify the specific role of representative tasks in capturing performance.

Anxiety

Anxiety is an aversive motivational state that occurs in threatening situations that leads to an increase in self-doubt and worrisome thoughts (Derekshan & Eysenck, 2009). It has been shown to negatively influence sporting performance and the underpinning mechanisms, including perceptual-cognitive skills. For example, Wilson, Wood and Vine (2009) had experienced basketball players take free throws under counterbalanced anxiety conditions (high and low-anxiety) whilst having their visual search measured. In the high-anxiety condition, there were fewer successful free throws and a decrease there was a decrease in quiet eye duration, when compared to the low-anxiety condition. Two theories have been forwarded to explain the effects of anxiety on performance. These are the *Processing Efficiency Theory* and the *Attentional Control Theory*.

Processing Efficiency Theory. Processing efficiency theory (PET; Eysenck & Calvo, 1992) was developed to provide specific predictions as to the effects of anxiety on performance. PET describes how anxiety results in attentional resources becoming focused on worrisome thoughts, leading to fewer resources being available in working memory for information processing and task completion (Baddeley, 1986). PET postulates that anxiety leads to an increase in motivation towards task completion. The additional motivation results in more on-task effort leading to additional recruitment of processing resources. A key tenet of PET is the distinction between *performance effectiveness* and *performance efficiency*. Performance effectiveness refers to the outcome of the task, whereas performance efficiency is defined as performance effectiveness divided by the amount of processing resources invested in the task (Eysenck & Calvo, 1992). The predictions of PET have been examined in various contexts, including karate (Williams & Elliott, 1999), soccer (Jackson, Kelly, Ashford & Norsworthy, 2006; Wilson et al., 2009), golf (Wilson, et al., 2007), darts (Oudejans

& Pijpers, 2009), and driving (Wilson, Chattington, Marple-Horvat & Smith, 2007). However, the main criticism of PET relates to its lack of detail on the effect anxiety has on the central executive system of working memory. It fails to explicitly identify the parts of the functionality of the central executive that are most affected by a significant increase in anxiety, such as maintaining task focus and switching between concurrent tasks.

Attentional Control Theory. Attentional control theory (ACT; Eysenck, Derekshan, Santos & Calvo, 2007) was created to provide clarification on the key limitation of PET, which is the impact of anxiety on the functionality of the central executive system. ACT describes how high-anxiety leads to a decrease in the ability to shift between concurrent tasks, as well as an inability to restrict or inhibit distractibility to irrelevant stimuli. The central tenet of PET remains within ACT in that there is a clear distinction between performance effectiveness and performance efficiency. ACT further describes how anxiety impacts on two types of attentional control within working memory (Baddeley & Hitch, 1974). The *goal-directed system* is involved in the preparation and execution of motor responses and is influenced by expectation, knowledge and current goals. The *stimulus-driven system* is concerned with the detection of salient or conspicuous stimuli (Corbetta & Shulman, 2002). ACT predicts that high-anxiety leads to a shift from a predominantly goal-directed to a more stimulus-driven strategy. The increased role of the stimuli-driven system is hypothesised to increase distractibility, coupled with attentional shifts to task-irrelevant stimuli and a decrease in efficiency of switching between tasks (Derekshan & Eysenck, 2009).

ACT further describes how performance effectiveness can be maintained as long as individuals allocate spare attentional resources to it. However, when too many attentional resources are spent attempting to identify and nullify the effects of anxiety, a decrease in performance effectiveness can occur. Evidence supporting PET and ACT was provided by Wilson et al. (2009) who examined experienced soccer players taking penalty kicks in high and low-anxiety conditions. In the high-anxiety condition, participants fixated vision for longer durations on the goalkeeper, indicating a stimuli-driven focus, and shorter durations on the target area, demonstrating a decrease in goal-directed focus, when compared to the low-anxiety condition. The decrease in visual attention toward goal-directed sources was accompanied by a decrement in shooting performance.

It appears that as the expertise level of an athlete increases so does their ability to limit the negative effect of anxiety on performance (Williams & Elliott, 1999). Expert athletes extensive practice history leads to them developing knowledge structures that require less attentional processes to complete tasks. Therefore, additional resources are available to locate and negate the sources of anxiety, thus further limiting the detrimental effects of anxiety. For example, Nibbeling et al., (2012) examined the impact of anxiety on expert and novice darts players. Participants completed a darts throwing task whilst carrying out a backward counting secondary-task. In a high-anxiety condition, both groups demonstrated a decrease in processing efficiency, through a less efficient visual search strategy. However, primary task performance outcome was negatively affected for the novice group, but not the expert group, when compared to a low-anxiety condition. Although the visual search behaviour of the expert group was affected by high-anxiety, they still maintained a more “expert like” strategy, as demonstrated by an earlier onset and longer duration of final fixation on the target. The visual search strategy of the expert group likely allowed sufficient time for the processing of information to take place, providing a possible explanation to their maintenance of performance on the primary task under high- compared to low-anxiety conditions, and when compared to the novice group.

Training perceptual-cognitive skill

Researchers have provided evidence that perceptual-cognitive skill is acquired through physical practice and activity that is structured in specific ways (Roca, Williams & Ford, 2012). For example, Ford, Low, McRobert and Williams (2010) examined the developmental activities of elite cricket players. They categorised players into high and low performing groups based upon their performance on a temporal occlusion test in which they anticipated bowling deliveries occluded around ball release. Subsequently, the developmental activities of participants were examined through a retrospective recall questionnaire. The high-performing group accumulated more hours in structured cricket activity, more hours in practice that mimicked match play, and fewer hours in the "nets" between 13-15 years of age compared to the low-performing group. These findings demonstrate the specific activities players should engage in during their development to acquire the perceptual-cognitive skills necessary for expert performance.

Other researchers have shown that perceptual-cognitive skills can be acquired through simulation training, such as that using video. In the next section, a review of research examining perceptual-cognitive skill training using simulation techniques is provided.

Perceptual-cognitive skill training

Researchers have shown that perceptual-cognitive skills can be enhanced through bespoke training interventions that simulate the real-world environment (Caserta, Young & Janelle, 2007). A common method is to use video-based tools to provide information linking the key cues in the display to the associated movement outcome (Hagemann, Strauss & Cañal-Bruland, 2006). The visual search behaviour adopted by expert performers is often highlighted to participants in an attempt to develop the link between cue and action. For example, Ryu, Kim, Abernethy and Mann (2013) examined the training of novice soccer goalkeepers who were attempting to anticipate penalty kicks. Participants were assigned to a guided perceptual-training group, an unguided perceptual-training group or a control group in a pre-, post-, 7-day and 24-hr retention test design. During training (n = 7 sessions) the guided perceptual-training group received information on the kinematic changes in the action and examples of the gold standard visual search behaviour of an expert goalkeeper. During each session they completed 64 trials in which they anticipated penalty kicks and they received feedback of performance on 50 % of trials. The unguided perceptual-training group completed the same amount of trials, but without any guidance, whereas the control group undertook no structured training. Only the guided perceptual-training group improved their anticipation performance between pre- and post-test, with this improvement being maintained in the retention tests. Data suggests tailored guidance and training can lead to maintainable performance improvements in perceptual-cognitive skill. However, this study used a sample of novice athletes and it is unclear as to whether the effects apply to athletes of a higher expertise level.

Other researchers (e.g., Causer et al., 2011) have demonstrated that expert athletes can benefit from perceptual-cognitive skill training. International-level skeet shooters were assigned to either a perceptual-training or a control group (Causer et al., 2011). During training, the perceptual-training group were provided with a detailed pre-shot routine, feedback on their own visual search and examples of visual search from an "expert shooter". The training was aimed at improving shooting accuracy through reducing the time to onset and increasing the duration of the final fixation prior to movement initiation (i.e., "quiet eye" period; Vickers, 1996). The control group received no form of perceptual-training and did not improve performance between the pre- and post-test. However, the perceptual-training group significantly increased their mean quiet eye duration, used an earlier onset of quiet eye and improved shooting accuracy from pre- to post-test. In a transfer test to performance during competition, the perceptual-training improved shooting accuracy, compared to pre-intervention. These findings demonstrate that perceptual training improves underlying perceptual-cognitive mechanisms leading to an improvement in performance in both the laboratory and competition environment.

A key consideration when designing training is that improvements in performance transfer to the real-world task (Broadbent et al., in press). In order for this transfer to occur, training interventions should contain tasks that are representative of the sporting domain. They should replicate the performance environment by containing similar perceptual, cognitive and motor requirements as the real-world version of the task. By doing so, the intervention enables athletes to refine their task-specific knowledge structures leading to them improving the processing of information and performance (Oudejans & Pjipers, 2009). These more ecologically valid approaches have been successful in improving perceptual-cognitive skills in a range of real-world sporting domains, including soccer (Wood & Wilson, 2012), tennis (Smeeton, Williams, Hodges & Ward, 2005) and cricket (Hopwood, Mann, Farrow & Nielson, 2011).

Real-world sport performance contains several stressors that are not typically present in the laboratory. Stressors, such as anxiety, have been shown to negatively impact upon several aspects of performance and it's underpinning perceptual-cognitive skills (Wilson, Smith, & Holmes, 2007). Therefore, research is required to examine whether the detrimental effects of anxiety can be mediated through training intervention involving high-anxiety conditions. For example, Oudejans and Pjipers (2009) demonstrated how training alongside high-anxiety lead to athletes being able to maintain the performance of perceptual-motor skills in future high-anxiety conditions. However, no research has investigated the impact of training alongside anxiety in relation to developing perceptual-cognitive skills.

Aims of thesis

The aim of this thesis was to examine the influence of high-anxiety, training and expertise-level on perceptual-cognitive skills in the sport of badminton. Specifically, a first aim is to examine the coupling between the kinematics of an action and the visual search behaviour associated with anticipating that action in badminton players ranging in expertise. A further aim is to investigate the effect anxiety has on perceptual-cognitive skills and how this interacts with the delegation of attentional resources. Another aim is to examine whether training perceptual-cognitive skills of expert players alongside high-anxiety conditions in a laboratory-based environment is an effective method for developing positive transfer to high-anxiety conditions and to more representative field-based tasks.

Researchers have examined visual search and anticipation judgements in isolation from the kinematics of the opponent action being observed. It is possible that when different visual search behaviour are found in this work they might be directly related to differences in observed kinematics. Chapter 2 examines the anticipation judgements and visual search behaviour of badminton players ranging in expertise level and how these are coupled to the kinematics of the opponent action being anticipated. In the first study, a kinematic analysis of international badminton players will highlight specific areas of the server that discriminate between service types.

Expert and novice players will complete a temporal occlusion test in which they will anticipate service direction/depth whilst having their visual search behaviour measured. It was predicted that the expert players would fixate vision upon the locations that discriminate between shot-type more frequently compared to the novice players. The between-group differences in visual search behaviour are expected to lead to a greater accuracy of anticipation judgement for the expert compared to novice players. Moreover, when fixating on areas of the opponent's body that discriminate shot type at the time in which they become discriminatory, both groups are predicted to have significantly more successful anticipation judgements compared to when fixating on other areas of the visual display.

World-class athletes and the performances they produce are rare and atypical of the standard expert population, so there is a need to examine the specific attributes underpinning their performances. Chapter 3 will investigate whether the relationship between the kinematics of an action and the visual search behaviour and anticipation of that action extends to a world-class player at the pinnacle of their sport. An exceptional expert player with outstanding careers achievements beyond those of other players will be compared to a representative international-standard expert and a representative novice player. Participants will complete a temporal occlusion test in which they will be required to anticipate the landing locations of a number of badminton serves while their visual search behaviour is recorded. The exceptional expert was expected to produce more accurate anticipation judgements compared to both the representative expert and representative novice. It was hypothesised that the exceptional expert will exhibit different visual search behaviour by fixating on the areas of the opponent's body that discriminate between serve-types more frequently and for longer durations compared to the other players.

The ability to delegate attentional resources to negating the detrimental effects of anxiety and to completing concurrent tasks is an important part of sport performance, but it may interact with the skill-level of the performer. Chapter 4 aims to examine the ACT theoretical framework (Eysenck et al., 2007) to explore how skill level influences the ability to mediate the effects of anxiety on anticipation judgements and the capacity to allocate attentional resources to concurrent tasks. Expert and novice badminton players will complete a temporal occlusion anticipation test in which they will be required to anticipate serve direction under counterbalanced anxiety conditions. On selected trials, participants will complete an auditory tone secondary-task. Expert players were predicted to outperform novices on the anticipation task across anxiety conditions. It was further expected that high-anxiety would result in decreased processing efficiency through an increase in mental effort and a change in visual search behaviour compared to low-anxiety conditions, with these results being stronger in the novice compared to expert players.

Training motor skill under high-anxiety conditions leads to performance being maintained in future high-anxiety conditions (Oudejans & Pjipers, 2009). However, there is a need to examine the impact of high-anxiety training on the acquisition of perceptual-cognitive skills. Chapter 5 will investigate whether training the perceptual-cognitive skills of elite level players alongside high-anxiety in a simulated task leads to positive transfer to both high-anxiety conditions and an *in-situ* field-based task. The intervention was predicted to lead to an increase in the accuracy of anticipation judgements that will transfer to an *in-situ* field-based task. It was further hypothesised that a group who trained alongside high-anxiety would maintain the accuracy of anticipation judgement in a transfer to similar high-anxiety conditions. In contrast, a group who trained under low-anxiety would decrease their level of a performance in the transfer to high-anxiety conditions.

In Chapter 6, the findings from the previous chapters are summarised and a theoretical framework is provided showing how perceptual-cognitive skills can be improved and made more robust under high-anxiety conditions. Future research directions are discussed and limitations of the programme of work are identified.

Chapter 2: The coupling between gaze behaviour and opponent kinematics during successful anticipation of badminton serves

The chapter originally presented here cannot be made freely available via LJMU Digital Collections because of copy right issues.

Chapter 3: Skilled anticipation in racket sports: Profiling an exceptional badminton player

The chapter originally presented here cannot be made freely available via LJMU Digital Collections because of copy right issues.

Chapter 4: The effects of anxiety on the anticipation performance, resource allocation and visual search behaviour of skilled and novice badminton players

The chapter originally presented here cannot be made freely available via LJMU Digital Collections because of copy right issues.

Chapter 5: Training under anxiety and the transfer of learning in elite performers

The chapter originally presented here cannot be made freely available via LJMU Digital Collections because of copy right issues.

Chapter 6: Epilogue

This chapter provides a synthesis of the work presented in the thesis and provides implications for both theory and practice. It identifies potential limitations of the work and possible future research directions are discussed.

Aims of the thesis

The aim of this thesis was to examine the influence of high-anxiety, training and expertise-level on perceptual-cognitive skills in the sport of badminton. The aim of the study in Chapter 2 was to examine the anticipation judgements and visual search behaviour of badminton players ranging in expertise level, as well as to investigate the link between these measures and the kinematics of the opponent action being anticipated. Chapter 3 examined whether the relationship between visual search behaviour and successful anticipation judgements extended to a world-class player. Previous work has shown that visual search behaviour and anticipatory performance are affected by anxiety (Williams & Elliott, 1999). Chapter 4 examined the role of skill level on the ability to mediate the effects of anxiety on anticipation judgements and the capacity to allocate attentional resources to concurrent tasks. Finally, Chapter 5 examined whether training the perceptual-cognitive skills of elite level players alongside high-anxiety led to positive transfer to both high-anxiety conditions and a field-based task.

Summary of key findings

Across the studies, expert players produced more accurate anticipation judgements of badminton serves compared to lesser-skilled groups and they exhibited different visual behaviours. In Chapter 2, expert players fixated locations that discriminated between serve types more often, and for a longer duration, compared to novice players. Irrespective of skill level, players produced more accurate judgements when they fixated upon the discriminating locations. Results support previous research showing that expert athletes produce highly accurate judgements by extracting advanced information from the postural cues of an opponent (Abernethy & Russell, 1987; Savelsbergh et al., 2002; Williams et al., 2002). Findings from Chapter 2 extend previous research by showing that the kinematics of opponent actions and the visual search behaviour of the athlete anticipating those actions are linked (Savelsbergh et al, 2002). In Chapter 3, the world-class athlete (EE) demonstrated a visual search strategy comprised of fewer fixations of a longer duration upon more information-rich areas of the display compared to the lesser-skilled athletes (RE, RN). Whilst the visual search behaviours of the EE were similar to those found for the other skilled athletes in Chapter 2 and 3, the EE fixated on key locations more often and for longer durations compared to those players. Data extends the area by showing that even highly skilled athletes have not got fully refined visual search strategies. This suggests that appropriate interventions can improve visual search strategies of expert as well as novice and less-skilled athletes.

In Chapter 4, increases in anxiety led to a decrease in the accuracy of anticipation judgements of serves on the primary task. High-anxiety resulted in a reduction in processing efficiency for both groups through an increase in mental effort and a significant decrease in the duration of final fixation. These findings support previous work showing that high-anxiety leads to an increase in compensatory strategies, such as additional cognitive effort, in an attempt to maintain the outcome of performance (Eysenck et al., 2007). However, for the expert group, the decrease in processing efficiency enabled them to maintain performance on the secondary tone reaction task in high- compared with low-anxiety condition. In contrast, high-anxiety resulted in a decrease in secondary task performance for the novice group when compared to the low-anxiety condition. The expert group were able to maintain performance effectiveness despite decreases in processing efficiency, supporting ACT. In contrast the decrease in processing efficiency for the novice group was associated with reduced performance effectiveness (Eysenck et al., 2007). For the expert group, the task was representative of their domain of expertise so the amount of resources required to complete it was lower compared to the novice group. Therefore, they had enough spare attentional capacity available to cope with the high-anxiety condition and for secondary task completion. Conversely, for the novice group, the primary task required a greater amount of attentional resources to complete compared to the expert group. Under high-anxiety conditions, the novice group did not have the attentional capacity to cope with those conditions and to complete the secondary task, thus leading to a decrease in secondary task performance.

It is predicted in ACT that a shift occurs in attentional control from a goal-directed to a more stimuli-driven focus under high- compared to low-anxiety conditions. The visual search behaviour from Chapter 4 did not support this prediction as the final fixation for both groups was still predominantly on the locations where the between-shot differences occur; suggesting that participants maintained a level of goal-directed attentional control (Wilson et al., 2009). In support of Chapters 2 and 3, the expert group maintained “expert-like” visual search behaviour, demonstrated by their longer final fixation duration to key locations when compared to the novice group, regardless of anxiety condition.

Given the detrimental effects to performance of the high-anxiety condition in Chapter 4, the study in Chapter 5 examined whether training under high-anxiety conditions would lead to anticipation performance being improved or retained in later high-anxiety conditions and in the field. Visual search behaviour and anticipation judgements were trained under either high- or low-anxiety conditions. The LA improved response accuracy in the low-anxiety post-test compared to both their pre-test score and a control group, as did the HA. Whilst there were no differences between training groups in the low-anxiety post-test, HA had greater response accuracy in the high-anxiety post-test compared to the LA and control groups. Results suggest the high-anxiety training did not lead to an ability to reduce anxiety or mental effort, but instead allowed for participants to adapt and recalibrate their behaviours to maintain performance outcome, supporting previous work showing this effect (Oudejans & Pijpers, 2009). Moreover, the training transferred to the field both training groups had greater response accuracy in the post-test compared to their pre-test, whereas the control group did not. Findings support previous research showing the transfer of skill acquisition from perceptual-cognitive skills training to the field (Smeeton et al., 2005; Williams et al., 2002)

This previous section has detailed and summarised the key findings from the thesis. The next section will discuss the implications of these findings for theory.

Implications for theory

Attentional Control Theory

ACT describes how a significant increase in anxiety can lead to a decrease in processing efficiency despite maintaining performance effectiveness. Anxiety is also thought to lead to an increase in attention to stimuli-driven sources, as opposed to goal-directed cues, and a decrease in either single task focus or the ability to switch between concurrent tasks (Eysenck et al., 2007). Chapter 4 extends ACT as a theoretical framework for identifying the effects of anxiety on performance by examining the interaction between skill-level and the ability to delegate attentional resources. Data showed that when expert players became anxious they were more efficient at allocating attentional resources to a concurrent task compared to lesser-skilled players.

These findings support and extend ACT as the expert group were able to maintain performance outcome compared to the less-expert group by increasing mental effort and using final fixations of a greater duration. Expert athletes have developed strategies for the encoding and retrieval of information in long-term memory, which leads to representative tasks demanding fewer attentional resources to complete. Therefore, additional resources within short-term working memory are available for the completion of concurrent tasks and to negate the detrimental effects of high-anxiety on performance. In contrast, less-skilled athletes do not have the same retrieval structures as a consequence of them not having the same amount or variety of domain-specific experience. As such, the representative task required a greater amount of attentional resources to complete. When they were presented with high levels of anxiety and a concurrent task, the limit of working memory was reached, resulting in a decrease in secondary task performance. Therefore, the less-skilled group were not able to maintain performance outcome by increasing mental effort when compared to low-anxiety conditions. Findings imply that gaining domain-specific experience leads to a reduction in the amount of required resources for task completion, which means additional resources can be allocated effectively elsewhere.

ACT was further extended in Chapter 5 by data showing that the ability to delegate attentional demands to tasks under high-anxiety conditions is trainable. Training under high-anxiety conditions allowed elite athletes to maintain anticipation performance in a later high-anxiety condition. In contrast, training under low-anxiety conditions meant that the LA group could not maintain performance under later high-anxiety conditions. These findings support previous work (Oudejans & Pijpers, 2009) showing that exposing athletes to high levels of anxiety during training enables them to develop effective self-regulatory processes for maintaining performance. Data from chapter 5 extends the earlier work of Oudejans and Pijpers (2009) by measuring the visual search behaviour and mental effort of athletes, providing measures of processing efficiency. According to ACT and the findings from Chapter 4, it was hypothesised that the HA group would maintain performance outcome by altering measures of processing efficiency to negate the detrimental effects of anxiety on performance, whereas the LA and CON would not. However, no differences were found as a function of anxiety condition and group for the measures of processing efficiency, including mental effort and visual search behaviour. The null effects from these measures of processing efficiency suggest the between-group anticipation performance differences in the high-anxiety post-test may be explained by related differences in attentional demands. Specifically, the training enabled the participants in the HA group to complete the task with fewer attentional resources, when compared to the LA and CON, resulting in the observed anticipation performance differences.

The Integrated Model of Anxiety

The results from Chapter 4 and 5 support aspects of the 'Integrated Model of Anxiety' detailed by Nieuwenhuys and Oudejans (2012). The model is similar to the earlier described distraction theories (i.e. ACT and PET) in that high-anxiety leads to an increase in additional effort. However, it postulates that this effort can be directed to reinforcing goal-directed processing, inhibiting stimulus-driven processing or attempting to reduce the levels of anxiety the individual experiences. In these studies, higher values were reported on the MRF-3 in the high- compared to low-anxiety conditions, so it does not appear that the additional effort lead to a reduction in experienced anxiety. In Chapters 4 and 5, the attentional control of participants was predicted to become more stimuli-driven under high-anxiety conditions, as opposed to goal-directed (ACT; Eysenck et al., 2007). Goal-directed attentional control refers to the preparation and execution of motor responses and is influenced by expectation, knowledge and current goals. In contrast, the stimulus-driven system is concerned with the detection of salient or conspicuous stimuli. The two systems are controlled by two distinct networks within the brain. First, the goal-directed system is controlled by the intraparietal cortex and superior frontal cortex. Second, the stimulus-driven system is mainly restricted to the right hemisphere and includes the temporoparietal cortex and inferior frontal cortex (Corbetta & Shulman, 2002). The visual search data from Chapters 4 and 5 suggest that the additional effort reinforced goal-directed processing and inhibited stimulus-driven processing, due to the final fixation being upon the discriminatory locations, regardless of anxiety condition. In Chapter 4, the increase in attention to maintain a goal-directed focus did not affect the performance of the expert group as they were able to complete the primary and secondary task successfully, regardless of anxiety condition. However, the less-skilled group required a greater amount of attentional resources to complete the primary task due to their limited domain-specific knowledge. The primary task coupled with the additional effort exerted to maintain a goal-directed focus resulted in fewer attentional resources being available for secondary task completion, leading to a decrease in secondary task performance.

The Integrated Model of Anxiety describes how anxiety may degrade performance due to shifts in the execution focus; specifically that high-anxiety leads to an internal- as opposed to external-focus of attention. Wulf and colleagues (for a review, see Wulf, 2013) have consistently shown that an internal-focus of attention degrades performance and learning of motor skills when compared to an external-focus of attention. The *action effect* hypothesis describes how for expert performers, having an internal-focus of attention is especially detrimental to performance as it leads to skills becoming deautomatized (Prinz, 1990). The increase in conscious control forces individuals to regress to earlier, less developed versions of the skill, negatively impacting on performance. The explicit monitoring of the skill might lead to greater mental effort in high- compared to low-anxiety conditions, which may in part explain this finding across the studies in this thesis. That is, in Chapter 4 and 5, high-anxiety may have lead to an internal-focus of attention, resulting in a decrease in performance. However as this wasn't directly measured this is only a supposition.

Perceptual-cognitive skills

The findings in this thesis support a number of concepts and hypotheses in the perceptual-cognitive skill literature, such as experts making more accurate anticipation judgements compared to lesser-skilled players. However, these concepts and hypotheses are yet to be made into an overarching model or theory for perceptual-cognitive skill performance. Visual search strategies are considered to be one of the underlying mechanisms by which individuals make anticipatory judgements (Williams et al., 2004), but they are observable behaviour, as opposed to theoretical behaviours. The ability of researchers to use eye movement registration systems to directly measure visual search behaviour, despite the limitations of this method, may be partly responsible for the lack of the theory in this area. Some of the findings for visual search behaviours contradict concepts and hypotheses in the perceptual-cognitive skill research (Abernethy & Russell, 19887; Savelsbergh et al., 2002; Shim et al., 2005; Williams et al., 2002). Previous work has tended to examine the kinematics of a movement and the visual search behaviour used to anticipate it in isolation, potentially producing contrasting findings. Research in tennis has shown expert players fixate vision towards proximal regions (e.g., torso and trunk) (e.g., Ward et al,. 2002). Alternatively, when anticipating badminton shots, expert athletes fixated upon distal areas of the body (arm and racket) (e.g., Abernethy & Russell, 1987), although these may be classified as a central location due to positioning of limbs. It is suggested that variation in the number of kinematic locations that differentiate between actions leads to a change in the locations of visual search fixations used to extract this information. In this thesis, visual search behaviours of expert players consisted of fewer fixations of a longer duration upon areas of the display in which between-serve differences were occurring. The fixation locations during successful anticipation judgements were the distal locations of arm, wrist and racket. It can be postulated that this visual search behaviour extended the period of time to both extract the required information from these postural cues of the server and to successfully link the observed cue to the forthcoming action (Abernethy & Russell, 1987). It allows time for information processing to occur between cue and action, whilst limiting the potential for the supressing of information as brought on through saccadic eye movements (Moran et al., 2002).

The findings in this thesis and from other researchers examining expert-novice differences in perceptual-cognitive skills support aspects of *deliberate practice* theory (for a review, see Ericsson, 2003). In this theory, the underlying mechanisms of performance, such as visual search strategies, are considered to be adaptations acquired from engaging in deliberate practice in the domain. The theory predicts that individuals who have engaged in greater amounts of domain-specific deliberate practice will produce superior levels of performance and acquire the necessary underlying mechanisms to underpin that performance when compared to individuals who had completed fewer deliberate practice hours. In Chapters 2, 3 and 4, it was observed that the expert players produced more accurate anticipation judgements compared to the less-expert players along with utilising different visual search behaviour. Therefore, more expert players would be expected to have engaged in greater amounts of deliberate practice compared to less-expert players, hence the observed differences in underlying mechanisms and performance. Moreover, deliberate practice theory predicts that the biological adaptations would be specific to the domain, and the task within the domain. Hence, in this thesis, badminton players anticipating serve direction from an opponent used fewer fixations of a long duration to distal areas of the server's body. In other studies examining other sports or tasks, visual search behaviours have been different. For example, when anticipating open-play tennis shots, players fixated on proximal regions (e.g., torso and trunk) (e.g., Ward et al., 2002). In comparison, in soccer match play, in which the environment is constantly changing requiring a constant updating of patterns and relative positioning (i.e. ball, teammates, opposition), skilled defenders made a greater number of short fixations to multiple locations (e.g., Roca et al., 2011). These findings show that visual search behaviours are specific to the sport and tasks within the sport.

Implications for practice

There are a number of practical implications that can be drawn from the thesis. The case-study design adopted in Chapter 3 allowed for the specific visual search behaviour that a world-class athlete exhibits during perceptual-cognitive judgements to be highlighted. Once identified, these attributes underpinning world-class performance can be used to help develop training interventions for refining well-established perceptual-cognitive skills of other elite players or those of less-skilled players. The high-anxiety training data from Chapter 5 provide a method for practitioners to help athletes adapt to anxious conditions. The results of the high-anxiety training from Chapter 5 supports the work by Oudejans and Pijpers (2010) who describe how training alongside high-anxiety allows athletes the opportunity to develop "adaptive processes". This leads to an increase cognitive effort thus developing more efficient self-regulatory processes. In this thesis, the LA and CON did not have the opportunity to establish these processes for high-anxiety conditions, meaning the additional effort was not directed to appropriate processes, leading to decreases in performance maintain performance (Oudejans & Pijpers, 2010). Practitioners should create training programmes with the aim of adapting and accelerating self-regulatory processes to enable athletes to adapt to high-anxiety conditions and maintain performance, as opposed to attempting to limit the amount of anxiety experienced.

In Chapter 5, the transfer of perceptual-cognitive skill from simulation training to the field was demonstrated. In this study, the training was all on-court, the video was life-sized, the participant was required to execute a 'shadow' shot, and a realistic time restriction was employed. Previous work has shown that visual search behaviour changes as a function of task fidelity, with higher fidelity between training and the transfer environment being more beneficial to learning and the associated visual search behaviours (Araujo, Davids & Passos, 2007; Dicks et al., 2010; Pinder, Renshaw, Headrick & Davids, 2013). In Chapter 5, athletes may have been able to recall in the field the acquired processes from the training as a result of the training containing similar constraints to the real-world version, thus potentially explaining the improvement in performance. Moreover, the training required participants to complete a shadow shot, which involved both perception and action processes. Maintaining perception-action coupling has been highlighted as a key part of simulation training (e.g., Dicks et al., 2010). Simulation training needs to encourage representative and adaptive decision-making, which is often in noisy or messy environments (Davids, Button, Araujo, Renshaw & Hristovski, 2006), to ensure effective transfer of behaviours to the real world version of the task (Travossos, Duarte, Villar, Davids & Araújo, 2012). Another aspect of perception-action coupling refers to the differentiation between the two streams of visual processing. Firstly, the *ventral stream* is recruited when perceiving information about a scene and, secondly, the *dorsal stream* becomes active during a movement and allows for online adjustments (Milner & Goodale, 1995). Through employing a shadow shot during the simulation training in Chapter 5, it can be argued that both streams of visual processing were engaged, as they are in the real world version of the task, thus leading to the positive transfer. The transfer from simulation training to the field shown in Chapter 5 suggest this method could be used by practitioners to improve these skills in the real world, particularly when such training closely matches the requirements of the real world version.

This thesis has provided an overview of the trainability and robustness of perceptual-cognitive skills of athletes ranging in expertise level. However, there are some limitations within the programme of work that are highlighted in the next section.

Limitations

A limitation of the thesis is that it only examined a few of the ACT hypotheses. The work from Eysenck and colleagues (2007) describes six specific hypotheses, of which this thesis only examined four. ACT provides specific hypotheses relating to the effects of anxiety on a number of central executive functions. These hypotheses relate to updating, task shifting, and task inhibiting. In this thesis, the hypotheses related to task shifting were examined. Therefore, conclusions drawn from the thesis are limited to those relating to this hypothesis and they do not take into account the untested hypotheses. A further limitation emanates from Chapter 5 and the finding that despite the HA making more accurate anticipation judgements compared to the LA in the high-anxiety post-test, there were no between-group differences in this test for the measures of performance efficiency (mental effort and visual search behaviour). It may be that between-group differences in attention may explain the between-group anticipation performance differences in the high-anxiety post-test. That is, the HA group may have acquired the ability to delegate attentional resources more effectively under later high-anxiety conditions compared to the LA. Therefore, although the high-anxiety training had a positive impact on performance under later high-anxiety conditions, it is unclear as to what impact the training had in regard to delegating attentional resources, as this was not examined in this study.

Another limitation of the thesis relates to the ACT framework and the way in which most of its measures of attention, such as self-report measures and visual search behaviour, are indirect in nature. Therefore, it is unclear as to how attention is allocated or the specific strategies individuals use to overcome working memory constraints. More direct measures of attention, such as neuroimaging or reaction time, may be required. Moreover, although ACT provides an extra level of scrutiny compared to its predecessor PET by identifying the effects of anxiety on the central executive within working memory, it appears that the theory is not falsifiable. ACT provides predictions for any feasible outcome when high anxiety is experienced, such as it leading to performance outcome being maintained when processing efficiency decreases, or vice versa. The only way it can be falsified is if a valid an extreme high-anxiety condition does not affect performance effectiveness or processing efficiency. If this were to happen, then the ACT framework does not provide any predictions as to why.

A further limitation of the thesis is the way in which it only examined the postural cue usage in anticipation judgements. By examining this cue in isolation, the other contextual variables surrounding the task that are present in the field, such as information related to the tactics, opponent characteristics and score characteristics, were not considered. These contextual variables have been shown to improve anticipation performance due to the greater amount of information available to the performer (McRobert et al., 2011). Another limitation is that despite the observed differences in perceptual-cognitive skills between expert and lesser-skilled players being predicted to be related to the amount of accumulated deliberate practice accumulated, this latter variable was not measured.

Another restriction of the thesis relates to the level of ecological validity of the laboratory-based task used in each chapter. Attempts were made to create a representative task throughout that was ecologically-valid (Travossos et al., 2013) Testing took place on-court, participants were required to complete a shadow shot return and strict temporal constraints were applied to responses. However, it could be argued that the two-dimensional video-based tasks may have failed to accurately represent the stimuli available for perception and action in the field. The described methods provided a significant level of reliability and validity in relation to producing controlled stimuli across testing conditions and participants, but the task may have decoupled the perception and action components. The laboratory-based task contained a set of limited potential options (n = 6), so the performance of the expert group may not have been representative of the way in which they would behave in the performance environment.

A related limitation is the way in which the expert participants in each study may have had prior knowledge of playing against the servers that were used in the video footage for the temporal occlusion tests. Through previous playing/training encounters, participants may have built up current event profiles relating to specific actions the servers tended to exhibit (McPherson, 1999). For example, a server may have a strong preference for playing a long serve to the tee when serving right-left. Therefore, the amount of direct previous experiences of and context surrounding the serves may have differed between participants and groups. Moreover, despite the badminton serve in doubles used throughout this thesis being identified by expert coaches as the shot requiring the most anticipation in doubles badminton, there is little, if any, empirical evidence supporting this. For example, in tennis, researchers have shown that very few shot types actually require players to move for them in an anticipatory manner. Rather, with most other shots, players are able to wait for a significant proportion of ball flight to occur before initiating a response (Triolet et al., 2013).

Future research

Eysenck and colleagues (2007) describe a number of specific hypotheses relating to the effects of anxiety on a number of central executive functions, of which this thesis only examined a sample. These hypotheses are about updating, task shifting, and task inhibiting. The task switching and inhibiting hypotheses state that high-anxiety reduces the ability to switch attentional focus between concurrent tasks and to limit distractibility to task-irrelevant stimuli. The updating hypothesis states that high-anxiety decreases the capability to refresh the central executive as to unfolding events. ACT describes how high-anxiety leads to individuals becoming more distracted by task irrelevant stimuli that are both external (e.g., presented by the experimenter) and internal (e.g., worrying thoughts; self-preoccupation). Future work should seek to examine the effects of skill level on mediating the effects of anxiety on these untested hypotheses of ACT, specifically the updating and inhibiting functions.

A method for examining the inhibiting hypothesis in ACT is to systematically quantify the amount of worrisome thoughts experienced during performance to show

how this interacts with the intensity of anxiety and the subsequent effects on performance. Quantifying the amount of worrisome thoughts, perhaps using verbal reports (Fox, Ericsson, & Best, 2013), would identify the amount of attentional resources being used up on irrelevant compared to goal-directed tasks. In order to assess the updating hypotheses, a research design could be employed in which participants are required to complete a primary task (i.e. anticipating badminton serve) whilst completing a concurrent prospective memory task in response to a cue (e.g., auditory or visual signal) under high-anxiety conditions. This methodology examines the capability of the central executive to update, adapt and respond to the specific requirements of the concurrent task. It would be predicted that high-anxiety would result in a decrease in performance on the secondary task due to participants being unable to *update* attention to that task when cued (Eysenck et al., 2007; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000).

In Chapter 5, the HA made more accurate anticipation judgements in the high-anxiety post-test compared to the LA. However, in this test, there were no between-group differences for the measures of performance efficiency (mental effort and visual search behaviour). One explanation for the between-group difference in anticipation judgements could be related to differences in attentional resource delegation strategies acquired from the different training protocols. That is, through exposure to high-anxiety training, the HA group may have acquired the ability to delegate attentional resources more efficiently and effectively under later high-anxiety conditions. Conversely, the low-anxiety training did not allow the LA to develop these strategies. In order to answer this, future work could encompass a methodology in which the distribution of attentional resources is measured directly. The most common method to achieve this is via a secondary task paradigm. A study with a similar methodology to that in Chapter 5, but with the addition of a discrete secondary task throughout the laboratory-based pre- and post-test sessions would provide specific evidence as to the attentional demands. The observed changes in anticipation performance as a function of training for the HA group in the high-anxiety post-test could be underpinned by acquired attentional resources being delegated in a more efficient and effective manner compared to that of the LA.

Chapter 3 demonstrated the potential to use case-study designs in order to identify the specific traits that contribute to world-class performance. Further work is needed within this area to gain a more detailed and holistic understanding of the mechanisms that underpin sporting excellence. Researchers should seek to incorporate tasks that hold the highest levels of both task functionality and action fidelity through the use of *in-situ* methods of data collection (i.e. field-based task in Chapter 6). There is a need for work that encompasses both a variety of sporting domains and a range of tasks within a specific domain (i.e. Roca et al., 2013). This will allow researchers to identify the mechanisms that underpin sporting excellence and draw conclusions as to whether they are a function of the sport or a specific task.

Chapter 5 investigated the impact of training perceptual-cognitive skills alongside high-anxiety. However, it is suggested that similar results may occur when training alongside other competition-like stressors. For example, Casanova, Garganta, Silva, Alves, Oliveira and Williams (2014) report how intermittent exercise resulted in a decrease in accuracy of anticipation judgements for both high and low level soccer players coupled with a decrease in the efficiency of visual search behaviour. Their data is similar to that found in the anxiety literature, as it demonstrates that competition-like stress negatively impacts both sporting performance and its underpinning mechanisms. Therefore, future work could potentially investigate the impact of training perceptual-cognitive skills under a "fatigue" like state in order to improve their robustness under those conditions later.

Concluding remarks

In conclusion, the experiments in this thesis have provided a detailed analysis of the relationship between the accuracy of anticipation judgements, visual search behaviour, kinematics and expertise, as well as how they interact with anxiety and training. The thesis highlighted the link between the kinematics of an action and the visual search behaviour used during anticipation of that action. The research has extended previous work by identifying the underlying mechanisms of perceptual-cognitive skills in world-class performance, whilst demonstrating the positive relationship found between anticipation skill, visual search and expertise extends to the pinnacle of the sporting world. The thesis identified the key role played by expertise in delegating attentional resources to concurrent tasks whilst making anticipation judgements under high levels of anxiety. The development and implementation of a perceptual-cognitive training intervention significantly improved performance in both practice and a real-world environment, whilst training alongside high-anxiety led to greater performance in similar conditions. Data have implications for research and theory, but also application in the elite performance sport setting in which these skills and their acquisition are key to expert performance. Overall, the results have broadened the perceptual-cognitive literature, contain both theoretical and practical implications, and have highlighted areas for future research.

References

Abernethy, B. (1990). Expertise, visual search and information pick-up in squash. *Perception, 19,* 63-77.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception, 30,* 233-252.

Abernethy, B., & Russell, D.G. (1987). The relationship between expertise and visual search strategy in a racquet sport. *Human Movement Science, 5,* 283-319.

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: The relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of Experimental Psychology: Applied, 18,* 143.

Abernethy, B., & Zawi, K. (2007). Pickup of essential kinematics underpins expert perception of movement patterns. *Journal of Motor Behaviour, 39,* 353-367.

Abernethy, B., Zawi, K., & Jackson, R, C. (2008). Expertise and attunement to kinematic constraints. *Perception, 37*, 931-48.

Allard, F., Graham, S., & Paarsalu, M. E. (1980) Perception in sport: Basketball. *Journal of Sport Psychology, 2,* 15-21.

Araujo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on Rogers, Kadar, and Costall (2005). *Ecological Psychology*, *19(*1), 69-78.

Baddeley, A. D. (1986). *Working Memory*. Oxford, UK: Clarendon Press.

Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation, 8,* 47-89.

Badminton Association of England (2005). *Level 1: Assistant coach training manual.* Milton Keynes, UK: BAE.

Behan, M., & Wilson, M. (2008). State anxiety and visual attention: The role of the quiet eye period in aiming to a far target. *Journal of Sport Sciences, 26,* 207-215.

Besson, M., Schön, D., Moreno, S., Santos, A., & Magne, C. (2007). Influence of musical expertise and musical training on pitch processing in music and language. *Restorative Neurology and Neuroscience, 25*, 399-410.

Bourne, M., Bennett, S. J., Hayes, S.J., & Williams, A. M. (2011). The dynamical structure of handball penalty shots as a function of target location. *Human Movement Science, 30,* 40-55.

Broadbent, D. P., Causer, J., Ford, P. R., & Williams, A. M. (in press). *European Journal of Sport Science.*

Calvo, M. G., & Eysenck, M. W. (1996). Phonological working memory and reading in test anxiety. *Memory, 4*, 289–305.

Cañal-Bruland, R., Lotz, S., Hagemann, N., Schorer, J., & Strauss, B. (2011). Visual span and change detection in soccer: An expertise study. *Journal of Cognitive Psychology, 23,* 302-310.

Caserta, R. J., Young, J., & Janelle, C. M. (2007). Old dogs, new tricks: training the perceptual skills of senior tennis players. *Journal of Sport and Exercise Psychology*, *29*, 479.

Casanova, F., Garganta, J., Silva, G., Alves, A., Oliveira, J., & Williams, A. M (2013). Effects of prolonged intermittent exercise on perceptual-cognitive processes. *Medicine and Science in Sports and Exercise, 45*, 1610-1617.

Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011) Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion, 11,* 595-602.

Causer, J., Janelle, C.M., Vickers, J. N., & Williams, A. M. (2012). Perceptual expertise: What can be trained? In: Hodges, N. J., &Williams, A. M. eds. *Skill Acquisition in Sport: Research, Theory and Practice.* London: Routledge. pp 306-324.

Causer, J., & Williams, A. M. (2013). Professional expertise in medicine. In *Catheter-Based Cardiovascular Interventions* (pp. 97-112). Springer Berlin Heidelberg.

Chase, W. G., & Simon, H. A. (1973). Perception in chess. *Cognitive psychology*, *4,* 55-81.

Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: a necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance, 2*7, 218.

Corbetta, M., & Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3,* 201-215.

Davids, K. W., Button, C., & Bennett, S. J. (2008). *Dynamics of skill acquisition: A constraints-led approach*. Human Kinetics.

de Groot, A. D. (1965). *Thought and Choice in Chess.* The Hague, Netherlands: Mouton.

Dempsey, A. R., Lloyd, D. G., Elliott, B. C., Steele, J. R., & Munro, B. J. (2009) Changing sidestep cutting technique reduces knee valgus loading. *American Journal of Sport Medicine, 37,* 2194-200.

Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: new developments from attentional control theory. *European Psychologist, 14,* 168–176.

Derakshan, N., Smyth, S., & Eysenck, M. W. (2009). Effects of state anxiety on performance using a task-switching paradigm: an investigation of attentional control theory. *Psychological Bulletin Review, 16,* 1112-1117.

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviours under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics, 72,* 706-720.

Ericsson, K. A. (2003). Development of elite performance and deliberate practice. In J. L. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports. Advances in research on sport expertise* (pp. 49-83). Champaign, IL: Human Kinetics.

Ericsson, K. A. (2008). Deliberate practice and acquisition of expert performance: a general overview. *Academic Emergency Medicine, 15,* 988-994.

Ericsson, K. A., & Delaney, P. F. (1999). Long-term working memory as an alternative to capacity models of working memory in everyday skilled performance. In A. Miyake, & P. Shah (Eds.), *Models of working memory: mechanics of active maintenance and executive control* (pp. 257-297). New York: Cambridge University Press.

Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*, 211-245.

Ericsson, K. A., & Lehmann, A.C. (1996). Expert and exceptional performance: evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47,* 273-305.

Eysenck, M. W., & Calvo, M., G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6,* 409-434.

Eysenck, M.W., Derakshan, N., Santos, R., & Calvo, M.G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7,* 336-353.

Eysenck, M. W., Payne, S., & Santos, R. (2006). Anxiety and depression: Past, present, and future events. *Cognition & Emotion, 20,* 274-294.

Farrow, D., & Abernethy, B. (2002). Can anticipation skills be learned through implicit video based perceptual training? *Journal of Sports Sciences, 20,* 471-485.

Farrow, D., Abernethy, B., & Jackson, R. C. (2005). Probing expert anticipation with the temporal occlusion paradigm: Experimental investigations of some methodological issues. *Motor Control, 9,* 330-349.

Fox, M. C., Ericsson, K. A., & Best, R. (2011). Do procedures for verbal reporting of thinking have to be reactive? *A meta-analysis and recommendations for best reporting methods. Psychological bulletin, 137*(2), 316.

Gabbett, T., Rubinoff, M., Thorburn, L.,& Farrow, D. (2007). Testing and training anticipation skills in softball fielders. *International Journal of Sports Science and Coaching, 2,* 15-24.

Gegenfurtner, A., Lehtinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualizations: a meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review, 23*, 523-552.

Gorman, A. D., & Farrow, D. (2009). Perceptual training using explicit and implicit instructional techniques: does it benefit skilled performers? *International Journal of Sports Science and Coaching, 4,* 193-208.

Hagemann, N., Strauss, B., & Cañal-Bruland, R. (2006). Training perceptual skill by orienting visual attention. *Journal of Sport and Exercise Psychology, 28,* 143.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers? *International Journal of Sports Science and Coaching, 6,* 523-536.

Huys, R., Smeeton, N. J., Hodges, N. J., Beek, P. J., &Williams, A. M. (2008). On the dynamic information underlying visual anticipation skill. *Perception & Psychophysics, 70,* 1217-34.

Jackson, R. C., Ashford, K., & Norsworthy, G. (2006). Attentional focus, dispositional reinvestment, and skilled motor performance under pressure. *Journal of Sport and Exercise Psychology, 28,* 49-68.

Jackson, R. C., & Mogan, P. (2009). Advance visual information, awareness and anticipation skill. *Journal of Motor Behaviour, 5,* 341-351.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychologica, 123,* 355-371.

Krane, V. (1994). The Mental Readiness Form as a measure of competitive state anxiety. *The Sport Psychologist, 8,* 89–202.

Kim, S., & Lee, S. (2006). Gaze behaviour of elite soccer goalkeeper in successful penalty kick defence. *International Journal of Applied Sport Science, 18,* 96-110.

Lees, A. (2002). Technique analysis in sport: a critical review. *Journal of Sports Sciences, 20,* 813-828.

Lewin, I. (1982). Driver training: a perceptual-motor skill approach. *Ergonomics, 25,* 917-924.

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 210-220.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29,* 457.

Maracora, S. M., Staiano, W., & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology, 106,* 857-864.

McPherson, S. L. (1999). Expert-novice differences in performance skills and problem representations of youth and adults during tennis competition. *Research Quarterly for Exercise and Sport, 70, 3,,* 233-251.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual-cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102,* 519-534

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*, 27.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49 –100

Moore, L. J., Wilson, M. R., Vine, S. J., Coussens, A. H., & Freeman, P. (2013). Champ or chump? Challenge and threat states during pressurized competition. *Journal of Sport & Exercise Psychology*, *35*, 551-562.

Moran, A., Byrne, A., & McGlade, N. (2002). The effects of anxiety and strategic planning on visual search behaviour. *Journal of Sports Sciences, 20,* 225-236.

Muller, S., Abernethy, B., & Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *Quarterly Journal of Experimental Psychology, 59*, 2162-86.

Murray, N. P., & Janelle, C. M. (2003). Anxiety and performance: A visual search examination of the Processing Efficiency Theory. *Journal of Sport & Exercise Psychology, 25*, 171-187.

Nibbeling, N., Oudejans, R. R. D., & Daanen, H. A. M. (2012). Effects of anxiety, a cognitive secondary task, and expertise on gaze behaviour and performance in a far aiming task. *Psychology of Sport and Exercise, 13,* 427-435.

Nieuwenhuys, A., & Oudejans, R. R. (2012). Anxiety and perceptual-motor performance: toward an integrated model of concepts, mechanisms, and processes. *Psychological* research, *76*, 747-759.

North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology*, *23*, 878-894.

Oudejans, R. R. D., & Nieuwenhuys, A. (2009). Perceiving and moving in sports and other high-pressure contexts. *Progress in Brain Research, 174,* 35-48.

Oudejans, R. R. D., & Pijpers, J. R. (2010a). Training with mild anxiety may prevent choking under higher levels of anxiety. *Psychology of Sport and Exercise, 11,* 44-50.

Oudejans, R. R. D., & Pijpers, J. R. (2010b). Training with anxiety has a positive effect on perceptual-motor performance under pressure. *The Quarterly Journal of Experimental Psychology, 62,* 1631-1647.

Panchuk, D., & Vickers, J. N. (2009). Using spatial occlusion to explore the control strategies used in rapid interceptive actions: Predictive or prospective control? *Journal of Sports Sciences, 27,* 1249-1260.

Pinder, R. A., Davids, K., Renshaw, I., & Araujo, D. (2011a). Representative learning design and functionality of research and practice in sport. *Journal of Sport & Exercise Psychology, 33,* 146-155.

Pinder, R. A., Renshaw, I., Headrick, J., & Davids, K. (2013). 19 Skill acquisition and representative task design. *Complex Systems in Sport, 7,* 319.

Poliszczuk, T., & Mosakowsk, M. (2009). Inter-reactions of peripheral perception and ability of time-movement anticipation in high class competitive badminton players. *Studies in Physical Culture and Tourism, 16,* 259-65.

Prinz, W. (1990). A common coding approach to perception and action, 167-201, Springer Berlin Heidelberg.

Reilly, T., Bangsbo, J., & Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. *Journal of Sports Sciences, 18,* 669-683.

Ripoll, H., Bard, C., & Paillard, J. (1986). Stabilization of head and eye movements on target as a factor in successful basketball shooting. *Human Movement Science, 5,* 47-58.

Ripoll, H., Kerlirzin, Y., Stein, J.F., & Reine, B. (1995). Analysis of information processing, decision making, and visual search strategies in complex problem solving sport situations. *Human Movement Science, 14,* 325-349.

Robbins, S., & Waked, E. (1998). Factors associated with ankle injuries. *Sports Medicine, 25,* 63-72.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2011). Identifying the processes underpinning anticipation and decision-making in a dynamic time-constrained task. *Cognitive Processing, 12*, 301-310.

Roca, A., Ford, P. R., McRobert, A. P., & Williams, A. M. (2013). Perceptual-cognitive skills and their interaction as a function of task constraints in soccer. *Journal of Sport & Exercise Psychology, 35,* 144-155.

Ryu, D., Kim, S., Abernethy, B., & Mann, D. L. (2013). Guiding attention aids the acquisition of anticipation skill in novice soccer goalkeepers. *Research Quarterly for Exercise and Sport, 84,* 252-262.

Salmela, J. H., & Fiorito, P. (1979). Visual cues in ice hockey goaltending. *Canadian Journal of Sport Sciences,* 4, 56-59

Savelsbergh, G. J., Van der Kamp, J., Williams, A. M., & Ward, P. (2005). Anticipation and visual search behaviour in expert soccer goalkeepers. *Ergonomics, 48,* 1686-1697.

Savelsbergh, G. J., Williams, A. M., Kamp, J. V. D., & Ward, P. (2002). Visual search, anticipation and expertise in soccer goalkeepers. *Journal of Sports Sciences, 20*, 279-287.

Shim, J., Chow, J. W., Carlton, L. G., & Chae, W. (2005). The use of anticipation visual cues by highly skilled tennis players. *Journal of Motor Behaviour, 2,* 164-175.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology: Applied,* 11, 98.

Spieler, M., Czech, D. R., Joyner, A. B., Munkasy, B., Gentner, N., & Long, J. (2007). Predicting athletic success: factors contributing to the success of NCAA division IAA collegiate football players. *Athletic Insight, 9,* 22-33.

Starkes, J. L. (1993). Motor experts: Opening thoughts. In J. L. Starkes & F. Allard (Eds.), *Cognitive issues in motor expertise* (pp. 3-15). Amsterdam, Netherlands: Elsevier.

Sternberg, R. J., Nokes, C., Geissler, P. W., Prince, R., Okatcha, F., Bundy, D. A., Grigorenko, E. L. (2001). The relationship between academic and practical intelligence: A case study in Kenya. *Intelligence, 29,* 401-418.

Thomas, J. R., Nelson, J. K., & Silverman, S. J. (1996). *Research Methods in Physical Activity*. Champaign, IL: Human Kinematics.

Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitao, J., & Cortinhas, A. (2013). Expertise effects on decision-making in sport are constrained by requisite response behaviours–A meta-analysis. *Psychology of Sport and Exercise, 14,* 211-219.

Travassos, B., Duarte, R., Vilar, L., Davids, K., & Araújo, D. (2012). Practice task design in team sports: Representativeness enhanced by increasing opportunities for action. *Journal of sports sciences, 30(13),* 1447-1454.

Triolet, C., Benguigui, N., Le Runigo, C., & Williams, A. M. (2013). Quantifying the nature of anticipation in professional tennis. *Journal of Sports Sciences, 31*, 820-830.

Van der Kamp, J., Rivas, F., Van Doorn, H., & Savelsbergh, G. J. P. (2008). Ventral and dorsal system contributions to visual anticipation in fast ball sports. *International Journal of Sport Psychology, 39,* 100-130.

Vickers, J. N. (1992). Gaze control in putting. *Perception, 21,* 117-132.

Vickers, J. N. (1996). Visual control while aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 342-354.

Ward, P., Farrow, D., Harris, K. R., Williams, A. M., Eccles, D. W., & Ericsson, K. A. (2008). Training perceptual-cognitive skills: Can sport psychology research inform military decision training? *Military Psychology, 20*, S71.

Ward, P., & Williams, A. M. (2003). Perceptual and cognitive skill development in soccer: The multidimensional nature of expert performance. *Journal of Sport & Exercise Psychology, 25,* 93-111.

Ward, P., Williams, A. M., & Bennett, S. J. (2002). Visual search and biological motion perception in tennis. *Research Quarterly for Exercise and Sport, 73,* 107-112.

Ward, P., Suss, J., Eccles, D. W., Williams, A. M., & Harris, K. R. (2011). Skill based differences in option generation in a complex task: A verbal protocol analysis. *Cognitive Processing, 12,* 289-300.

Wheeler, K. W., Wiseman, R., & Lyons, K. (2011). Tactical and technical factors associated with effective ball offloading strategies during the tackle in rugby league. *International Journal of Performance Analysis in Sport, 11,* 392-409.

Williams, A. M., & Burwitz, L. (1993). Advance cue utilization in soccer. *Science and Football II,* 239-244.

Williams, A. M., & Elliott, D. (1999). Anxiety, expertise, and visual search strategy in karate. *Journal of Sport & Exercise Psychology*, *21,* 362-375.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. Research Quarterly for Exercise and Sport, 69, 111-128.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science, 24*, 283-307.

Williams, A. M., & Ford, P. R. (2008). Expertise and expert performance in sport. *International Review of Sport and Exercise Psychology, 1,* 4-18.

Williams, A. M., Ford, P. R., Eccles, D. W., & Ward P. (2011). Perceptual-cognitive expertise in sport and its acquisition: Implications for applied cognitive psychology. *Applied Cognitive Psychology, 25*,432-42.

Williams, A. M., & Grant, A. (1999). Training perceptual skill in sport. *International Journal of Sport Psychology, 30*, 194-220.

Williams, A. M., Hodges, N. J., North, J. S., & Barton, G. (2006). Perceiving patterns of play in dynamic sport tasks: Investigating the essential information underlying skilled performance. *Perception*, 35, 317.

Williams, A. M., & Reilly, T. (2000). Talent identification and development in soccer. *Journal of Sports Sciences, 18,* 657-667.

Williams, A. M., & Ward, P. (2003). Perceptual expertise: Development in sport. *Expert Performance in sports: Advances in research on sport expertise,* 219-249.

Williams, A. M., Ward, P., Bell‐Walker, J., & Ford, P. R. (2012). Perceptual-cognitive expertise, practice history profiles and recall performance in soccer. *British Journal of Psychology, 103*, 393-411.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton N. J. (2002). Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *Journal Experimental Psychology: Applied, 8*, 259-70

Williams, A. M., Ward, P., Smeeton, N. J., & Allen, D. (2004). Developing anticipation skills in tennis using on-court instruction: Perception versus perception and action. *Journal of Applied Sport Psychology, 16,* 350-60.

Williams, A. M., Vickers, J. N., Rodrigues, S., & Hillis, F. (2002) Anxiety and performance in Table tennis: a test of Eysenck and Calvo's processing efficiency theory. *Journal of Sport and Exercise Psychology, 24, 438-455.*

Wilson, M. R., Chattington, M., Marple-Horvat, D. E., & Smith, N. C. (2007). A comparison of self-focus versus attentional explanations of choking. *Journal of Sport and Exercise Psychology, 29,* 439.

Wilson, M. R., Smith, N. C., & Holmes, P. S. (2007). The role of effort in influencing the effect of anxiety on performance: Testing the conflicting predictions of processing efficiency theory and the conscious processing hypothesis. *British Journal of Psychology, 98,* 411-428.

Wilson, M. R., Vine, S. J., & Wood, G. (2009). The influence of anxiety on visual attentional control in basketball free throw shooting. *Journal of Sport and Exercise Psychology, 31, 152-168.*

Wilson, M. R., Wood, G., & Vine, S. J. (2009). Anxiety, attentional control, and performance impairment in penalty kicks. *Journal of Sport and Exercise Psychology, 31,* 761-775.

Wood, G., & Wilson, M. R. (2012). Quiet-eye training, perceived control and performing under pressure. *Psychology of Sport and Exercise, 13,* 721-728.

Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology, 6,* 77-104

Vine, S. J., Freeman, P., Moore, L. J., Chandra-Ramanan, R., & Wilson, M. R. (2013). Evaluating stress as a challenge is associated with superior attentional control and motor skill performance: Testing the predictions of the biopsychosocial model of challenge and threat. *Journal of Experimental Psychology: Applied, 19*, 185.

Zijlstra, F. R. H. (1993). Efficiency in work behaviour: *A design approach for modern tools. Delft*, the Netherlands: Delft University Press.